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SALES hereby certify that annexed is a true copy of the Provisional specification  
in connection with Application No. 2002951892 for a patent by BHP BILLITON  
INNOVATION PTY LTD as filed on 09 October 2002.



WITNESS my hand this  
Thirteenth day of October 2003

*J R Yabsley*

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**MINING PROCESS AND DESIGN****FIELD OF THE INVENTION**

The present invention relates to the field of extracting resource(s) from a particular location. In particular, the present invention relates to the designing and  
5 processing of a mine location in a manner based on enhancing extraction of material considered of value, relative to the effort and / or time in extracting that material.

**BACKGROUND ART**

In the mining industry, once material of value, such as ore situated below  
10 the surface of the ground, has been discovered, there exists a need to extract that material from the ground.

In the past, one more traditional method has been to use a relatively large open cut mining technique, whereby a great volume of waste material is removed from the mine site in order for the miners to reach the material considered of  
15 value. For example, referring to Figure 1, the mine 1 is shown with its valuable material 2 situated at a distance below the ground surface 3. In the past, most of the (waste) material 4 had to be removed so that the valuable material 2 could be exposed and extracted from the mine 1. In the past, this waste material was removed in a series of progressive layers 5, which are ever diminishing in area,  
20 until the valuable material 2 was exposed for extraction. This is not considered to be an efficient mining process, as a great deal of waste material must be removed, stored and (later) returned to the mine site 1, in order to extract the valuable material 2. It is desirable to reduce the volume of waste material that must be removed prior to extracting the valuable material.

25 The open cut method exemplified in Figure 1 is viewed as particularly inefficient where the valuable resource is located to one side of the pit 5 of a desirable mine site 1. For example, Figure 2 illustrates such a situation. The valuable material 2 is located to one side of the pit 5. In such a situation, it is not considered efficient to remove the waste material 4 from region 6, that is where  
30 the waste material is not located relatively close to the valuable material 2, but it is considered desirable to remove the waste material 4 from region 7, that is where it is located nearer to the valuable material 2. This then brings other considerations to the fore. For example, it would be desirable to determine the

boundary between regions 6 and 7, so that not too much undesirable waste material is removed (region 6), yet enough is removed to ensure safety factors are considered, such as cave-ins, etc. This then leads to a further consideration of the need to design a 'pit' 5 with a relatively optimal design having consideration for the location of the valuable material, relative to the waste material and other issues, such as safety factors.

This further consideration has led to an analysis of pit design, and a technique of removing waste material and valuable material called 'pushbacks'. This technique is illustrated in Figure 3. Basically, the pit 5 is designed to an extent that the waste material 4 to be removed is minimised, but still enabling extraction of the valuable material 2. The technique uses 'blocks' 8 which represent smaller volumes of material. The area proximate the valuable material is divided into a number of blocks 8. It is then a matter of determining which blocks need to be removed in order to enable access to the valuable material 2. This determination of 'blocks 8', then gives rise to the design or extent of the pit 5. Figure 3 represents the mine as a 2 dimensional area, however, it should be appreciated that the mine is a 3 dimensional area. Thus the blocks 8 to be removed are determined in phases, and cones, which represent more accurately a 3 dimensional 'volume' which volume will ultimately form the pit 5.

Further consideration can be given to the prior art situation illustrated in Figure 3. Consideration should be given to the scheduling of the removal of blocks. In effect, what is the best order of block removal, when other business aspects such as time/value and discounted cash flows are taken into account? There is a need to find a relatively optimal order of block removal which gives a relatively maximum value for a relatively minimum effort/time.

Attempts have been made to find this 'optimum' block order by determining which block(s) 8 should be removed relative to a 'violation free' order. Turning to the illustration in Figure 4, a pit 5 is shown with valuable material 2. For the purposes of discussion, if it was desirable to remove block 14, then there is considered to be a 'violation' if we determined a schedule of block removal which started by removing block 14 or blocks 14, 12 & 13 before blocks 9, 10 and 11 were removed. In other words, a violation free schedule would seek to remove other blocks 9, 10, 11, 12 and 13 before block 14. (It is important to note that the

block number does not necessarily indicate a preferential order of block removal). It can also be seen that this block scheduling can be extended to the entire pit 5 in order to remove the waste material 4 and the valuable material 2.

With this violation free order schedule in mind, prior art attempts have been made. Figure 5 illustrates one such attempt. Taking the blocks of Figure 4, the blocks are numbered and sorted according to a 'mineable block order' having regard to practical mining techniques and other mine factors, such as safety etc and is illustrated by table 15. The blocks in table 15 are then sorted 16 with regard to Net Present Value (NPV) and is based on push back design via Life-of-mine NPV sequencing, taking into account obtaining the most value block from the ground at the earliest time. To illustrate the NPV sorting, and turning to Figure 4, there is a question as which of blocks 9, 10 or 11 should be removed first. All three blocks can be removed from the point of view of the ability to mine them, but it may, for example, be more economic to remove block 10, before block 9. Removing blocks 9, 10 or 11 does not lead to 'violations' thus consideration can be given to the order of block removal which is more economic. The NPV sorting is conducted in a manner which does not lead to violations of the 'violation free order', and provides a table 17 listing an 'executable block order'. In other words, this prior art technique leads to a listing of blocks, in an order which determines their removal having regard to the ability to mine them, and the economic return for doing so.

There still exists a need, however, to improve this prior art technique. Given that mining projects, on the whole, are relatively large scale operations, even small improvements in prior art techniques can represent millions of dollars in savings, and / or greater productivity.

An object of the present invention is to provide an improved method of block removal, and / or an improved pit design and / or executable block order.

Another object of the present invention is to alleviate at least one disadvantage of the prior art.

### 30 SUMMARY OF THE INVENTION

The present invention provides, in one aspect, in a system and method of determining the removal of material(s) of a differing relative value from a location, including:

Determining the approximate volume of material to be removed,  
 Dividing the volume to be removed into at least two blocks,  
 Attributing a relative value to each block,

the improvement including:

- 5       Sorting each of the blocks according to its value,  
        Listing each block and its associated value in a table, irrespective of  
 violation(s).

In essence, this aspect serves to grade blocks in value order, such as  
 highest to lowest. One benefit is that, in a given time, the most valuable return  
 10       may be obtained from the blocks that are extracted. Preferably, the block list  
 above may be re-sorted to reduce violations. This provides improved accuracy  
 and / or practicality to the order of block removal.

The present invention also provides, in a second aspect, a system and  
 method of reducing violations in the removal of material(s) in block(s) of a  
 15       differing relative value from a location, the system or method including:

- Selecting a block,  
        Determining a cone corresponding to the selected block,  
        Determining violations attributed to the cone,  
        Determining a new position of the cone with reference to reduced  
 20       violations.

In essence, this aspect serves to provide a relatively improved or  
 substantially violation free order of the block extraction order. Reducing violations  
 improves the ability or difficulty in extracting blocks.

The present invention also provides, in a third aspect, a system and  
 25       method of reducing violations in the removal of material(s) in block(s) of a  
 differing relative value from a location, the system or method including:

- Selecting a block,  
        Determining a cone corresponding to the selected block,  
        Determining violations attributed to the cone,  
 30       Determining a new position of the cone with reference to improved NPV.

In essence, the third aspect serves to determine an extraction order which  
 takes into account (at least partially) issues of business accounting, such as NPV,  
 being Net Present Value. This aspect takes into account that, in a given time, the

most valuable return may be obtained from the blocks that are extracted substantially corresponding to a block extraction order determined at least partially in accordance with the principles of NPV. Preferably, the second and third aspects are both taken into consideration.

- 5 In the removal of material(s) in block(s) of a differing relative value from a location, the present invention provides, in a fourth aspect, a system and method of determining a new cone position in a stack, the system or method including:

Determining a number of violations associated with a first cone position,

- 10 Determining a number of violations associated with a second cone position, the second cone position having less than or an equal number of violations as the first cone position,

Selecting as the new cone position, the second cone position.

Preferably, the second cone position is determined iteratively and / or randomly. This aspect of the invention serves to improve violation free orders.

- 15 It is important to note that, although the term violation free is used in the specification, this is not intended to mean that the entire order is violation free. The order may still include violations. The violations may be reduced in number, or at least not increased in number or difficulty.

- 20 Throughout the specification, although reference is made to 'a block' or 'blocks', it is to be noted that this should not be limited to some sort of cubic shape. A block(s) may refer to a region, volume or area of any dimension. Furthermore, reference to a (single) block may also represent a number of blocks.

- 25 In a similar way, if a first collection of blocks are to be removed, second and / or more corresponding collection(s) of blocks, which are pointed to by the first collection of blocks, are also to be removed prior to removal of the first collection of blocks.

#### **DESCRIPTION OF PREFERRED**

Preferred embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

- 30 Figures 1 to 5 illustrate prior art mining techniques,  
Figure 6 illustrates a representation of a mine pit,  
Figure 7 illustrates one aspect of the present invention,  
Figure 8 illustrates a second aspect of the present invention,

Figure 9 illustrates a third aspect of the present invention and.

Figures 10A and 10B illustrate a second embodiment of the present invention.

Preferred embodiments of the present invention, and their associated aspects are described, for simplicity, in a two dimensional form. It will be understood that the principles and techniques disclosed are equally applicable to three dimensional situations.

The present invention assesses inputs, such as ultimate pit, block values, slope constraints, mining rate and discount factor, and provides as an output an extraction time ordering of blocks that substantially maximises NPV and respects pit slope constraints.

Figure 6 represents an illustration of a pit 5 of a mine 1. The pit represents a volume of material that is to be removed. The pit is divided into (say) 6 blocks. Each block is identified by references A, B, C, D, E, and F. The value of each block is determined with reference to known criteria, such as:

- Selling price of ore per tonne,
- tonnage of ore contained in block,
- vertical position of block in pit,
- type of surrounding rock,
- cost of mining,
- cost of processing block,
- cost of selling block.

These factors may be taken into consideration to obtain a net value for a block.

As will be described in more detail with reference to Figure 10A, a number of the blocks form a cone. The cone is (usually) a three dimensional volume, taking into account more practical aspects of mining, such as various parameters, value, LUT and block model(s).

According to the first aspect of the present invention, the blocks are sorted according to their value and further processed or stored (in a table) accordingly. An example is illustrated in Figure 7, where table 18 lists the blocks from highest value block to lowest value block. This aspect is considered unique, in as much as prior art techniques, first determine the listing of blocks according to the ease of mining each block, rather than (first) determining the listing of the blocks

according to their value. One benefit of the present aspect is that by listing the blocks according to value, a global aspect is given to the local search that is performed subsequently. During the block/cone repositioning phase of a preferred form of the invention, the various aspects see nearby block orderings (this is from the "local" aspect). These aspects are therefore of a type of myopic or short sighted local search. This can be enhanced by starting the block ordering valued from highest to lowest, thus giving a somewhat 'global' perspective to the invention.

Of course, the listing may be from lowest value to highest value, and the execution of the list may be done in reverse order. The principle is to determine a listing of blocks in a 'value order' so that removal of the blocks from the pit can be accomplished in an order presenting value. In a commercial aspect, the highest value is sought to be obtained in the quickest time, and thus the highest value block is sought to be mined the earliest so a relatively quick return can be obtained on the investment in the mining project.

As can be seen in Figure 7, there are a number of violations, represented in the diagram by arrows pointing downwards. The violations occur as it is considered to be a violation to remove block 600, before first removing blocks located above it (as show in Figure 6). Therefore, in a second aspect of the present invention, the blocks of table 18 are sorted to remove at least one violation, and again further processed or stored (in a table) accordingly. This is represented in Figure 8 and table 19. Table 19 as shown has 3 downward pointing arrows, and thus 3 violations.

A third aspect of the present invention is illustrated in Figure 9 and table 20, in which the listing of table 19 are re-sorted having regard to improving NPV, but without increasing the number of violations. Once again, the re-sorted list is further processed or stored (in a table) accordingly. NPV is increased in table 20, relative to table 19 in as much as block E of 500 value heads the table in table 20, whereas in table 19, block D of value 40 headed the table.

The present invention (preferably) then continues to (iteratively) process the tables to reduce violations and NPV, in accordance with the aspects illustrated in Figures 8 and 9. Preferably, the further processing continues until little or no further benefit can be obtained. At that point in time, the listing of the



blocks is considered complete, resulting in what may be referred to as an executable block order, and removal of material in accordance with the list can be undertaken. Of course material can be removed in accordance with a partially iterated listing of blocks, but this may not be what is considered to be an 'optimal' listing of blocks. Figure 9 shows an indication of time, giving some effect to a sequence of execution of the determination made in accordance with the present invention.

Figures 10A and 10B illustrate a second embodiment of the present invention, more specifically directed to implementing the invention as used in the mining industry. Figure 10A illustrates, in schematic form, a system for calculating cone construction and implementing the first aspect disclosed above. A number of the blocks (as described in Figure 4) form a cone. The cone is (usually) a three dimensional volume, taking into account more practical aspects of mining, such as various parameters, value, LUT and block model(s).

Block\_model 21 is calculated based on X, Y, Z, rock type, metal grades, tonnages (earth/metal).

The various parameters 22 include block dimensions (X,Y,Z), number of blocks (NX, NY, NZ), recoveries (how much per block is recoverable), slope constraints, and cost model parameters.

Value 23 is calculated based on (XYZ \$). The ways of valuing each block may be the same as those described above in reference to Figure 6. The (X Y Z \$) simply describes a preferred form of a file format. The calculation of block values relies on many parameters, some of which are listed in reference to Figure 6 above. Some of the information input to the present invention may be in the form of two-dimensional arrays. These arrays have four columns, namely x, y, z, \$. Each row of this type of array refers to a single block, and the columns for entries of this row refer to the X coordinate, Y coordinate, z coordinate, and value, respectively.

The block model, parameters and value are used to calculate arcs 24. Given a particular block, we must calculate which arcs will emanate from the block, that is, which other blocks are pointed to by that block. How many blocks must be removed depends on the slope of the pit wall at that position in the pit. Different rock types require different slopes. Those rock types that are more

prone to collapse require lower maximum slopes than those types of rocks that are not so prone to collapse. Mining engineers/geologists provide maximum slopes angles for each coordinate/block in the pit. Slope constraints may be encoded by inter-block arcs. Based on the slope angle, one can extrapolate an inverted cone with apex at the particular block in question. Any blocks above the particular block in question that are contained within this cone should be pointed to or identified, either directly or indirectly, by the particular block in question.

Arcs, value, parameters and cube LUT are used as an input to a look up table 25. The output of the lookup table provides what is referred to as optimal NPV ordering of extraction 26. This is input to Figure 10B and which is described in more detail below.

LUT(LookUp Table) is calculated based on value, and  $LUT(Nblocks)(1+\max(narcsout)+\max(Naresin))$ . By way of explanation, imagine that the three-dimensional grid representing the elements to be extracted contained in an open pit can be represented as a three dimensional array. Within this three dimensional array, each element represents a block. Using the kind of construction described above, it is relatively easy to determine which blocks are pointed to by another block. However, the block/cone repositioning of the present invention uses blocks on a "stack" and does not directly use the three-dimensional coordinates of a block. Therefore a look up table is used to convert between a block number and its three-dimensional coordinates. In one embodiment of the present invention, we use four distinct look up tables, each of which represents aspects of table 25 and which are highlighted in the dotted block 25a.

Firstly, to calculate the value of a block 25b, second to calculate the arrows pointing into a block 25c, thirdly to calculate the arrows pointing out of a block 25d.

- The look up table to calculate the values of a block 25b uses criteria, such as that described with reference to Figure 6 above,
- The look up table for calculating the arrows pointing into a block 25c consists of a two-dimensional array. This array has a number of rows equaling the number of blocks in the pit. The number of columns is equal to the maximum number of arcs pointing in to any block. Each row of this

array contains block numbers of blocks pointing into the block represented by that row'

- Likewise the look of table for calculating the arrows pointing out of a block 25d consists of a two-dimensional array. This array has a number of rows equaling the number of blocks in the pit. The number of columns is equal to the maximum number of arcs pointing out of any block. Each row of this array contains block numbers of blocks pointing out of the block represented by that row, and
- A 4th look up table 25e serves to correlate block numbers with their three-dimensional coordinates in the pit.

The LUT is sorted in accordance with the first aspect of the present invention, in which the blocks are sorted into a table in accordance with each block's value, and which is described above.

Figure 10B illustrates, in schematic form, a system for implementing the second and third aspects described above, which preferably takes input from Figure 10A. The second aspect of the present invention is denoted 27. The third aspect of the present invention is denoted 28.

In explaining the Figures 10A and 10B, it is to be noted that the 'optimal' NPV ordering of extraction may not be an order of extraction which is most practical in the field to implement. Therefore, Figure 10B applies a further series of processes to the output of Figure 10A, with the aim of optimising (further) the order of extraction.

In explaining Figure 10B, assume that the analysis begins at the top of a stack. The stack height is incremented by 1 at block 29, that is the next entry in the stack. A cone is determined 30 based on this entry, and any violations are determined 31. Where the present invention is making an initial determination, the Nvio (Number of Violations) may be reset at block 32.

At block 33, it is determined whether there are any violations. If there is not, path 34, then it is determined whether there are any more entries to be analysed 35. If it is the last entry, then the analysis ends at 36. If there are more entries to analyse, then the depth is incremented at 37, and the next cone collection is determined once again at block 30. If there are violations, a cone is configured 38, and this is placed on top of the stack 39. This is somewhat akin to

the swapping of the highest as described with reference to Figure 8 above, however, as will be described below, the exact positioning of the cone has yet to be determined. The number of violations 40 are again determined.

Block 28 (dotted) represents an embodiment of the second aspect of the present invention. That is the entry and associated cone are further processed to determine more optimal NPV, but with no more violations. In this regard, block 41 determines the number of violations for position(s) of the cone under consideration. The cone is moved along the stack 42 where a position of possible violation decrease is found. Have any positions been found where there is a violation decrease at 43? If a position(s) has been found, path 45 leads to a determination of those positions 46, and at 47 the position with the best (considered) position is determined. The cone is then placed in that position 48, and the position is saved 49. The next entry is then analysed again starting at block 29. If there has not been any improvement in decreasing the number of violations at 43, path 44 returns to consider a number of alternatives. One alternative is to return to consideration of the next entry in the stack at block 37. Another alternative 51, is to find the various (other) cone positions where the number of violations did not increase 52, and thereafter calculate the corresponding NPV for those other positions 53. The cone can then be moved to the position which has best considered NPV. As a further alternative 54, a new cone position can be selected randomly, with a bias to selecting positions with an improved NPV. The cone may then be placed 48 and stored 49 in this position. The saved state 49 also gives a listing of the current stack. This may be used at any time as the executable block order.

Although the description above describes the analysis of the various stack entries being 'moved', this may not necessarily happen in a physical sense. The various processes and determinations in accordance with the present invention may be performed by way of reference to a database, coordinate or positioning of in a recording medium. A listing or representation of improved extraction information is sought as an output of the invention.

#### OTHER ISSUES

The present invention may incorporate better estimate of optimal cut-off grade in block valuation:

an improvement over marginal cut-off grade can dramatically affect NPV, (and probably the optimal pushback design). Therefore some consideration of cut-off grade should be included in pushback design.

The present invention may incorporate separate mining and processing  
5 rates:

timing of blocks depends on both the mining and processing rates. To more accurately estimate extraction time and improve the NPV-valuation model, proper consideration of processing time should be included in push back design.

The present invention may take into consideration blending aspects:

- 10 • Deposits such as iron ore and coal provide new challenges, as the end products are typically created by blending together several blocks from the block model.
- The final value of a block is therefore *unknown* until it has been blended with other blocks.
- 15 • Block values cannot be considered in isolation when designing pushbacks, extraction schedules, and even the ultimate pit!, but must be considered in conjunction with other (possibly spatially separated) blocks in the ore reserve.
- A proper treatment of this aspect to rigorously maximise NPV is needed.
- 20 The present invention may take into consideration stochastic aspects:
- The value assigned to a block in a three-dimensional block model is a single deterministic value.
- In reality, the exact value is unknown and some blocks contain greater uncertainty than others (this uncertainty can be estimated via conditional  
25 simulations of the orebody).
- Pushbank designs that take into account the risk associated with ore grade uncertainty and aim for risk-minimal/return-maximal extraction schedules are needed.

As the present invention may be embodied in several forms without  
30 departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present invention unless otherwise specified, but rather should be construed broadly within the spirit and scope of the invention as defined in the appended claims.

**13**

**Various modifications and equivalent arrangements are intended to be included within the spirit and scope of the invention and appended claims.**

1

**THE CLAIMS DEFINING THE INVENTION AREAS FOLLOWS:**

1. A method of determining the removal of material(s) of a differing relative value from a location, including:

Determining the approximate volume of material to be removed,

Dividing the volume to be removed into at least two blocks,

Attributing a relative value to each block,

the improvement including:

Sorting each of the blocks according to its value,

Listing each block and its associated value in a table, irrespective of violation(s),

Re-sorting the table listing to reduce violations.

2. A method of reducing violations in the removal of material(s) in block(s) of a differing relative value from a location, the method including:

Selecting a block,

Determining a cone corresponding to the selected block,

Determining violations attributed to the cone,

Determining a new position of the cone with reference to reduced violations.

3. A method of reducing violations in the removal of material(s) in block(s) of a differing relative value from a location, the method including:

Selecting a block,

Determining a cone corresponding to the selected block,

Determining violations attributed to the cone, and

Determining a new position of the cone with reference to improved NPV.

4. In combination, a method as claimed in claim 2 and 3.

5. In the removal of material(s) in block(s) of a differing relative value from a location, a method of determining a new cone position in a stack, the system or method including:

Determining a number of violations associated with a first cone position,

Determining a number of violations associated with a second cone position, the second cone position having less than or equal number of violations as the first cone position,

Selecting as the new cone position, the second cone position.

6. A method as claimed in claim 5, wherein the second cone position is determined iteratively.

7. A method as claimed in claim 5, wherein the second cone position is determined randomly.

8. A system for determining the removal of material(s) of a differing relative value from a location, including:

First means determining the approximate volume of material to be removed,

Second means dividing the volume to be removed into at least two blocks,

Third means attributing a relative value to each block,

the improvement including:

Sorting means for sorting each of the blocks according to its value,

Means for listing each block and its associated value in a table, irrespective of violation(s), and

Re-sorting means for re-sorting the table listing to reduce violations.

9. A system for reducing violations in the removal of material(s) in block(s) of a differing relative value from an allocation, the system including:

Selecting means for selecting a block,

Determining means for determining a cone corresponding to the selected block,

Violation determining means for determining violations attributed to the cone, and

Position determining means for determining a new position of the cone with reference to reduced violations.



## 16

10. A system of reducing violations in the removal of material(s) in block(s) of a differing relative value from a location, the system including:

Block selecting means for selecting a block,

Cone determining means for determining a cone corresponding to the selected block,

Violation determining means for determining violations attributed to the cone,

Position determining means for determining a new position of the cone with reference to Improved NPV.

11. In combination, a system as claimed in claim 9 and 10.

12. In the removal of material(s) in block(s) of a differing relative value from a location, a system for determining a new cone position in a stack, the system including:

means for determining a number of violations associated with a first cone position,

means for determining a number of violations associated with a second cone position, the second cone position having less than or an equal number of violations as the first cone position,

means for selecting as the new cone position, the second cone position.

13. A system as claimed in claim 12, wherein the second cone position is determined iteratively.

14. A system as claimed in claim 12, wherein the second cone position is determined randomly.

15. A computer program product including:

A computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining the removal of material(s) of a differing relative value from a location, within a data processing system, said computer program product including:

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Computer readable code within said computer usable medium for displaying determining the removal of material(s) of a differing relative value from a location in accordance with anyone of claims 1 to 7.

16. A method or system as herein disclosed.

DATED this 9th day of November 2002

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Figure 1  
(prior art)

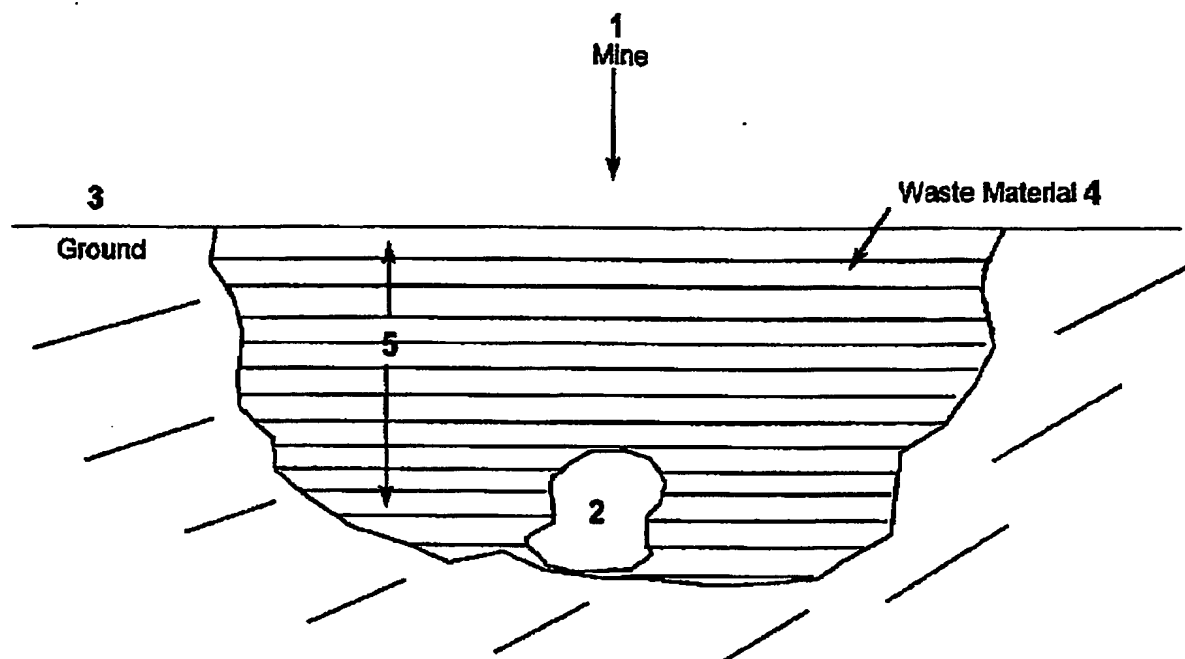


Figure 2  
prior art

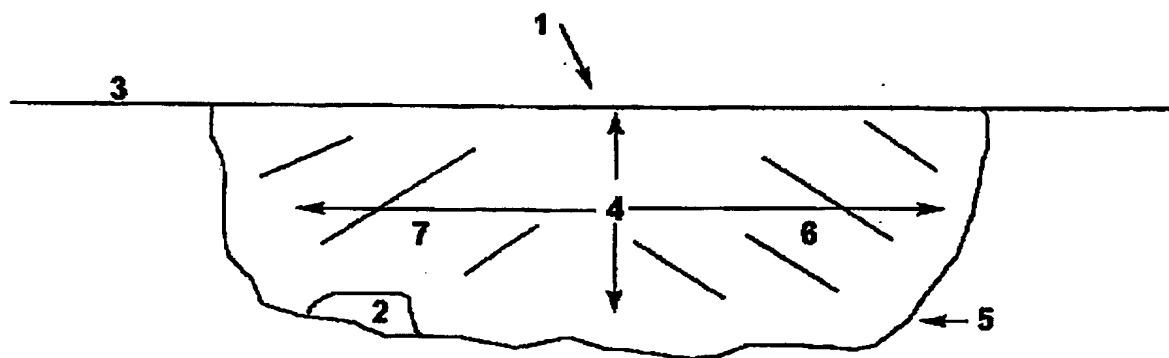


Figure 3  
prior art

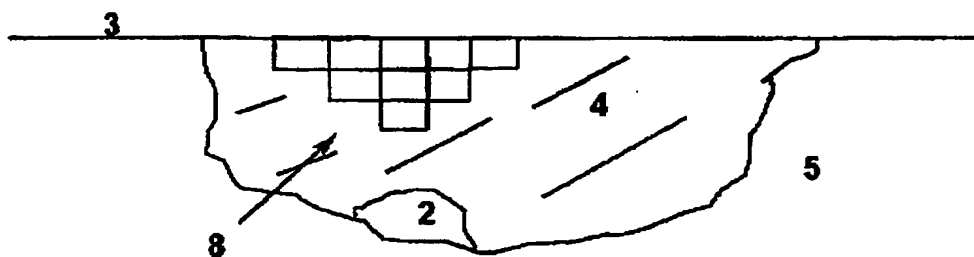


Figure 4  
prior art

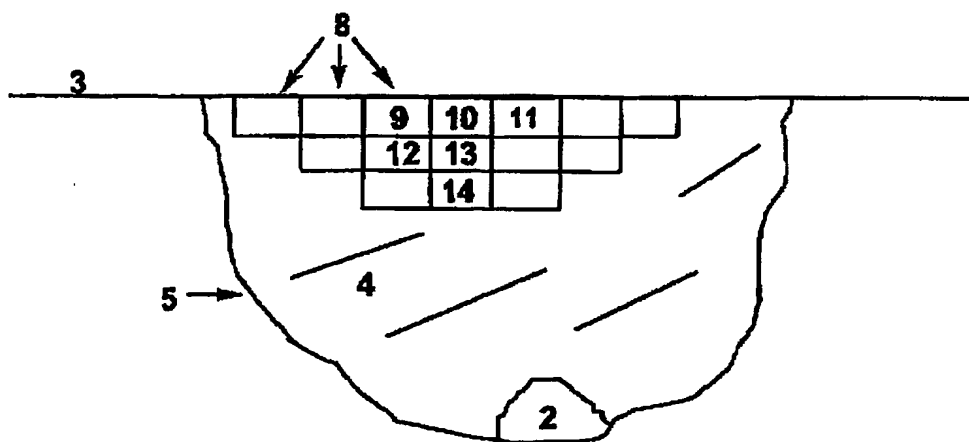


Figure 5  
prior art

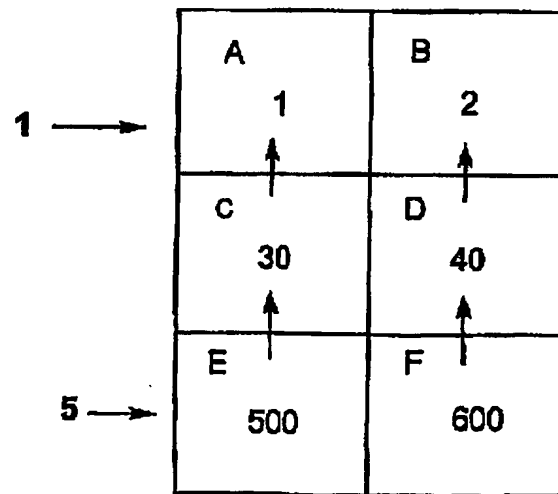
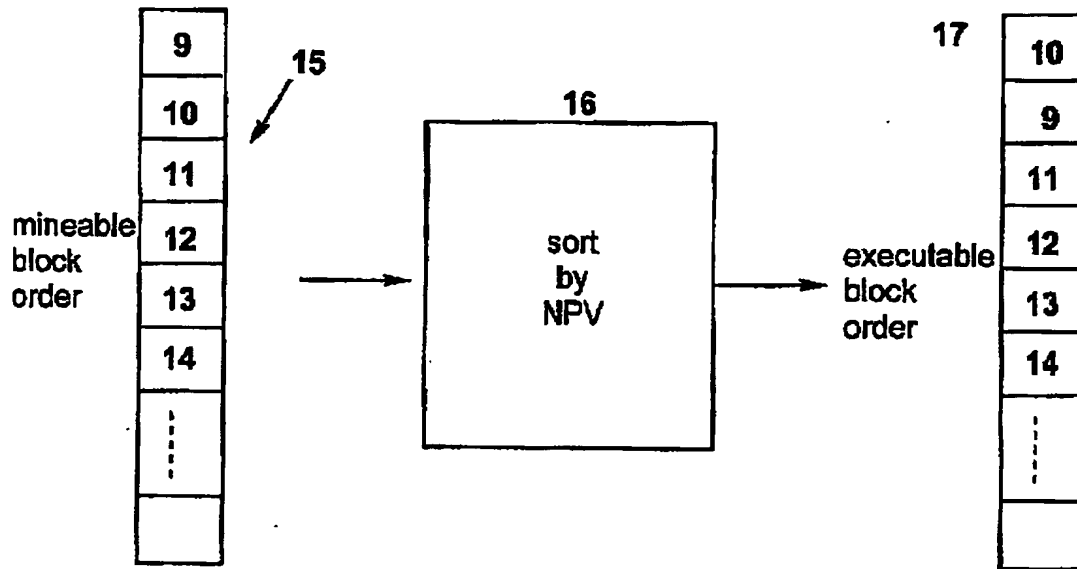
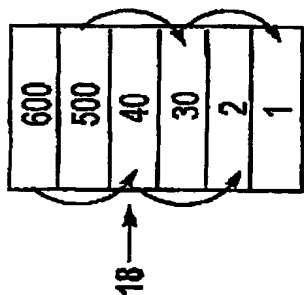


Figure 6

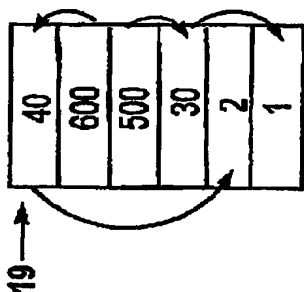
highest to lowest



4 down arrows  
= 4 violations

Figure 7

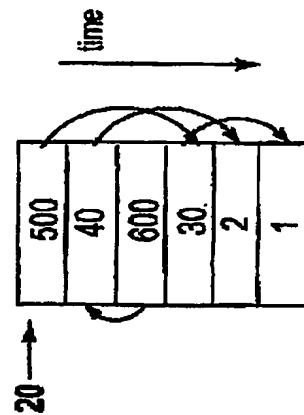
then swap highest



3 down arrows,  
the 3 violations

Figure 8

then order for better NPV  
by moving 'cone' (up  
arrow blocks) but with no  
more violations



3 violations

Figure 9

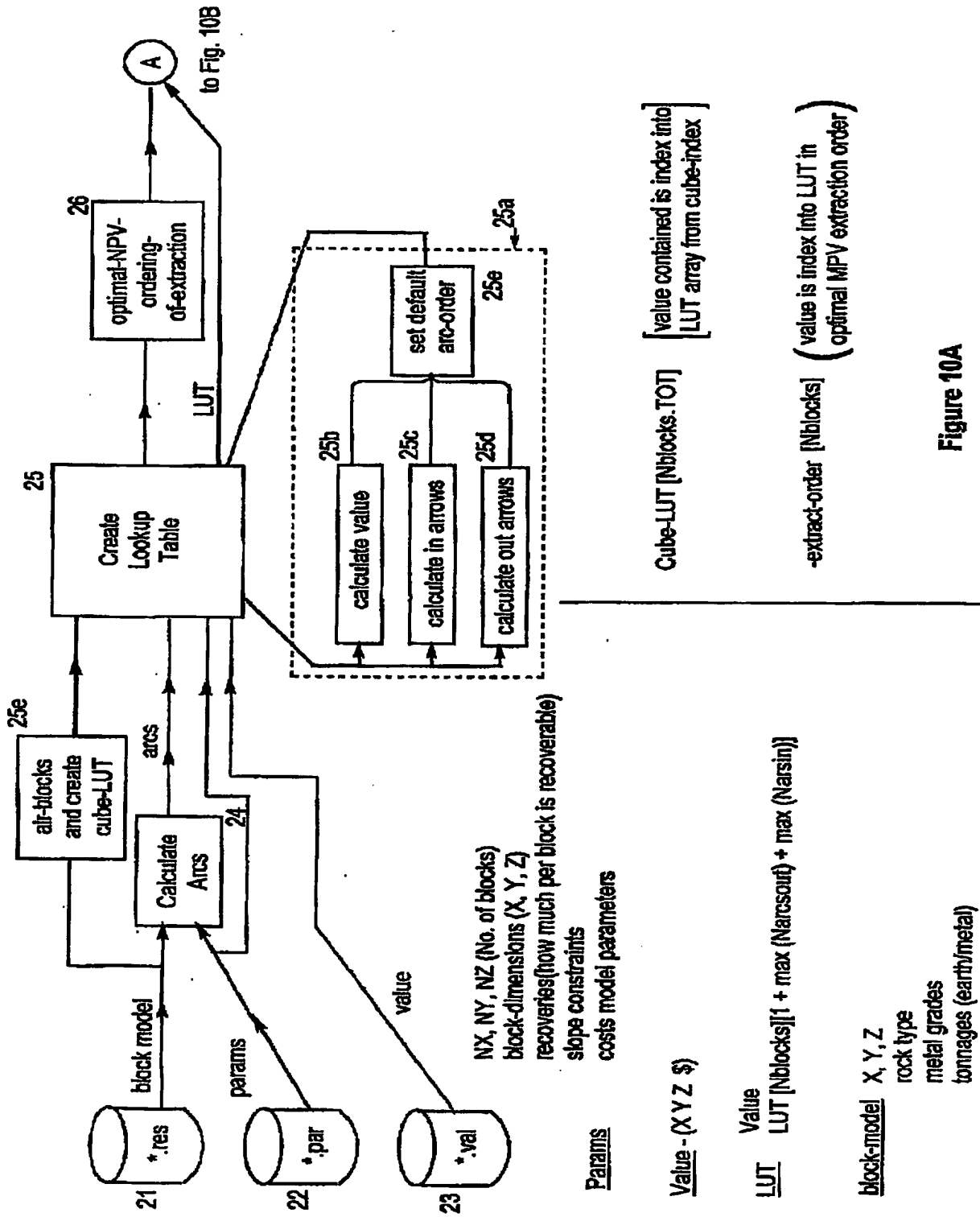


Figure 10A

